Evidence for a Western Extracontinental Land Source During the Devonian Period in the Central Andes

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ABSTRACT

A large intracratonic sedimentary basin of mid-Paleozoic age in the central Andes apparently received sediments from a western land source. Lithofacies and isopach data show a thickening and general textural coarsening to the north and west in the Devonian rocks of Bolivia. Early to early Middle Devonian onlap and offlap are recognized. Rate of subsidence in the basin was only slightly exceeded by rate of sedimentation, because the youngest Devonian beds recognized are either very shallow marine (in southern localities) or nonmarine (in at least one northern locality). Devonian brachiopod community studies suggest that a shallow marine environment persisted in the region throughout the time of deposition of the Devonian rocks. An absence of bedded carbonate rocks indicates a cold-climate environment of deposition. It is suggested that the source area yielded abundant muscovite. Outcrops of sialic basement relicts in the Cordillera Occidental are concluded to be portions of a buried land mass. *Key words: stratigraphic geology, Devonian, Bolivia.*

INTRODUCTION

In the central Andes, as much as 4,000 m of clastic sedimentary rocks were deposited over a region of about 1.6×10^6 km² within a 20- to 23-m.y. time span during the Devonian Period. This region, herein called the central Andean intracratonic basin, occupied the present area of northern Argentina, the Paraguayan Chaco, all of Bolivia, and southern to central Peru (Fig. 1) at one time or another. Lithofacies studies and isopachs of the Bolivian portion of the basin suggest that most of the Devonian sediments were derived from a large western land source area including a mass then situated beyond the present-day western continental margin of South America.

James (1971, p. 3340) summarized the Paleozoic history of the central Andes by including the Devonian in "undeformed Paleozoic deposits totaling 10 to 15 km in thickness," with these deposits being chiefly on the Paleozoic continental shelf and slope. He further characterized the region by including relicts of a sialic crust to the west of these rocks and termed the origin of this crust "an enigma." This paper proposes to unite James's (1971) "relicts" with a hypothetical land mass of sialic composition to the west of the central Andes that yielded most of the Bolivian Devonian sediments. Preliminary calculations of sedimentary volume suggest that the surface area of the Pampean uplifts (suggested by Harrington [1967] as a source) and (or) the area of outcrop of James's (1971) crust are insufficient to supply the volume of Devonian sediments in the central Andean intracratonic basin even at the lowest estimate, unless these western peripheral belts were uplifted more than 1 to 2 km.

No eugeosynclinal sediments exist in any Devonian section measured. As far as can be determined to date, no volcanic rocks or volcanogenic sediments exist in the central Andean Devonian sections. Similarly, it appears that no flyschlike sediments exist in the region. No cyclic bedding or grading within beds is apparent. The presence of ripple marks does not suggest a flysch origin of the sediments. The occurrence of articulated shallow marine brachiopods (see discussion below) throughout most of the sections further precludes such an origin. Gradational, and in places abrupt, contacts between beds of differing lithology are interpreted as being a change in the epeirogenic-eustatic land-sea relations or as changes in the rate of erosion of the source area.

PREVIOUS WORK

An eastern source area with a geosyncline to the west has been proposed by some, and a southwestern source supplying an intracratonic (or pericratonic) basin by others. Kozlowski (1923, p. 7) suggested that the bulk of the Bolivian Devonian was deposited in a shallow marine basin, with the western portion being deposited in a slightly deeper basin. Chamot (1969) concurred with this view and suggested that the main source for the sediments was the "Central Brazilian upland" to the east. Weeks (1947, p. 80–81) stated that an Early Devonian transgression from the west deposited "thousands of meters of flysch type sediments" in the "Cordilleran trough area of Bolivia and south Peru." Ahlfeld and Branisa (1960, p. 69–70) suggested that a geosyncline occupied the area of

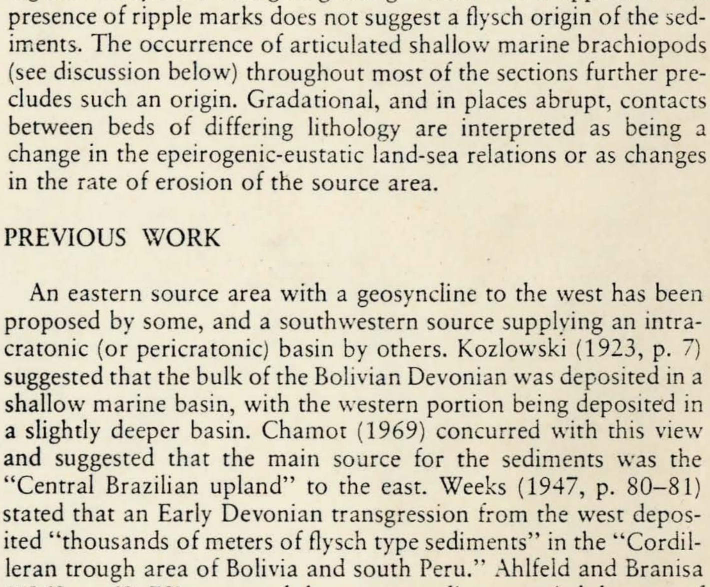

Figure 1. Map of central Andes region, showing locations of measured sections.

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Geological Society of America Bulletin, v. 86, p. 39–46, 4 figs., January 1975, Doc. no. 50106.

central to northwestern Bolivia, as the Devonian sequence there is thicker and the rocks tend to be finer in grain size than the southern Bolivian sequence. Padula (1959, p. 9) proposed a eugeosyncline in northwestern Bolivia and a miogeosyncline in the Sierras Subandinas region of east-central Bolivia. Lohmann (1970, p. 740) concluded that contorted "Middle or Late Devonian" black shale and fine-grained sandstone in northern Bolivia suggested the end of a "geosynclinal deep-sea phase" there.

Amplifying the view of Bonarelli (1921), that the Pampean massifs of northwestern Argentina and southern Bolivia supplied sediments to the Devonian rocks of the Cordillera Oriental and the Sierras Subandinas of Bolivia, Harrington (1967, p. 655) suggested that "the axis of maximum subsidence and accumulation is reached along the present Subandean Ranges," with the Pampean uplifted areas yielding transported sediments from the west. Sonnenberg (1965, p. 39) suggested some sediments were contributed from the rejuvenation of the Pampean massif in "mid-Devonian time."

In the terminology of Kay (1951, p. 17), the Devonian sediments of Bolivia were deposited in an exogeosyncline, with no miogeosynclinal and eugeosynclinal elements of an orthogeosyncline. The region might be compared to King's (1969, p. 49) "successor basin" model, although the tectonic history of the area remains too speculative to permit such a characterization.

Only three areas of Bolivia have been described in any stratigraphic detail. Knowledge of the character of the Devonian strata of northwestern Bolivia came from Ahlfeld and Branisa (1960), Fricke and others (1964), and Wolfart and Voges (1968). Central Bolivia was described by Ahlfeld and Branisa (1960) in less detail, although Chamot (1969, unpub. data) supplied detailed stratigraphic information for the Icla locality (Fig. 1) in south-central Bolivia. Information on the Chiquitos area of eastern Bolivia came from Barbosa (1948), Ahlfeld (1956), and Chamot (1963). Ahlfeld and Branisa (1960) offered the best synthesis of stratigraphic information beyond a limited geographic region, and Schlatter and Nederlof (1966) offered the first comprehensive paleogeographic summary. Information for the Argentine and Paraguayan portions of the central Andean intracratonic basin is from Padula and others (1967, p. 168), who described the Devonian of the northwest basin of Argentina as being thinner than that across the frontier in Bolivia, and stated that, from time to time during the Devonian, the uplifted "Puna and Pampean Arch" contributed locally conglomeratic units to the east. The Paraguayan Chaco consists of approximately 2,000 m of Lower Devonian shale and silty shale (Harrington, 1956, p. 107; Eckel, 1959, p. 68), with a thinner, sandier facies to the east (Wolfart, 1961, p. 57–58).

DISCUSSION

Marine Sediments

The Devonian marine strata contain abundant detrital muscovite, most of which is unweathered. Bedded carbonate rocks and evidence for reef-dwelling organisms are absent, with the possible exception of the Los Monos section. Clarke (1913, p. 26) and Ahlfeld and Branisa (1960, p. 70) concluded that the environment of deposition throughout the region was very cool in Devonian time — too cool to favor the existence of many lime-precipitating microorganisms. The presence of detrital mica indicates that mechanical rather than chemical decomposition was dominant in the source area. Any carbonate deposition that may have taken place was probably masked by terrigenous deposition, especially in the thicker western sections. Many clastic rocks have some carbonate cement.

Strata containing argillaceous carbonate nodules have been observed by Chamot (unpub. data) and by me. Weeks (1953) interpreted such carbonate nodules as being syngenetic carbonate precipitation around an organic nucleus that continued until the nodule was buried by terrigenous material. Calcareous nodules are abundant at the Icla–Cha-kjeri, Quilco, and Presto localities, whereas the size and abundance of such nodules decrease in the northwestern localities of Ayo Ayo and Belén. This may indicate a higher rate of sedimentation in the north than elsewhere. The nodules occur only in the middle argillaceous portions of depositional sequences, not in the lower and upper parts.

Nonmarine Sediments

Few nonmarine sedimentary rocks are recognized in the Bolivian Devonian strata, if one ignores the various age assignments (Dávila and Rodríguez, 1967; Wolfart and Voges, 1968) given to the quartzite below the Devonian. A definite shallowing trend has been recognized in gross aspect by Boucot (1971, p. 38), and in detail by me (Isaacson, 1974b) at one locality. All sections exhibit a shallowing trend, although only the Belén-Pujravi section records nonmarine sedimentation. This section, with several units of quartzose sandstone, has halite solution pits in the uppermost beds. Careful field examination indicates that the sandstone is unfossiliferous. Although the lack of fossils and gross lithologic character suggest at least littoral or supratidal deposition, the presence of nonmarine sediments can be determined only when the silty interbeds are examined for the presence or absence of marine phytoplankton (acritarchs).

Base of the Devonian

Branisa (1960, 1969) and Branisa and others (1972) have drawn the Silurian-Devonian boundary between the quartzite and siltstone-sandstone that is briefly described in the sections listed in Appendix 1. Inasmuch as the upper part of the quartzite is unfossiliferous, its age is controversial. Because Silurian fossils (for example, the brachiopods *Clarkeia*, *Harringtonina*, and some trilobites) exist in the lower part of the quartzite, the entire unit is now assigned Silurian age for convenience in estimating the position of the base of the Devonian strata throughout the Andean region.

Time Span for the Devonian Sequence

Estimates made by Boucot and others (1969), Boucot (1971), and by me (Isaacson, 1974a) place the time range of late Siegenian through late Emsian or early Eifelian as the amount of time involved for deposition of most of the Bolivian Devonian sequence — less than 20 m.y. In summary, because Givetian and younger faunas are generally considered to be cosmopolitan, their absence in Bolivia suggests that beds younger than Eifelian in Bolivia (Kozlowski, 1923; Ahlfeld and Branisa, 1960; Schlatter and Nederlof, 1966; Harrington, 1967; Wolfart and Voges, 1968) are not present. Also, occurrences of several Early Devonian brachiopod genera and species near the tops of some of the sections lend additional support to an Early Devonian age for most of the strata.

Paleoecologic Considerations

The following environmental assignments have been proposed for the Malvinokaffric Realm (a geographic region including most of southern South America, South Africa, and Antarctica during Early Devonian time), based on the brachiopod community scheme proposed by Ziegler (1965) and developed by Boucot (1971, 1974) and by me (Isaacson, 1974a): In Benthic Assemblage (BA) 1 (high intertidal zone) are homalonotid trilobites, most bivalves, orbiculoid and linguloid brachiopods, and some trace fossils. The *Globithyris* Community occupies a position that includes parts of both BA 1 and BA 2 (Isaacson, 1974b). Most of the terebratuloid brachiopods found in the Malvinokaffric Realm are in BA 2 (low intertidal zone). Terebratuloid genera include *Scaphiocoelia*, *Pleurothyrella, Derbyina,* and *Mutationella.* Included in BA 2 is the *Tropidoleptus* Community. Larger chonetid, spiriferid, and schuchertellid brachiopod communities occupy a BA 3 position (shallow subtidal zone). The deepest communities recognized are the *Metaplasia* and *Austronoplia* (n. gen.) Communities, which occupy a BA 4 and 5 (mid- to outer-shelf) position. BA 6 (continental slope zone) has no brachiopod representatives. No beds appear to have been deposited in an environment deeper than the shelf edge (200 m).

Although most of the fossils recovered from localities in the Bolivian Devonian strata do not appear to have been preserved in life position, it is unlikely that they underwent long-distance transportation. Boucot (1974) summarized this question and emphasized that it was unlikely for shells to accumulate in large quantities very far from their growth site in the shallow marine environment.

Unconformity

An angular unconformity between the Devonian and younger beds has been observed in most of the measured sections. Depending upon the locality, the unit above the unconformity ranges from Carboniferous sandstone to Tertiary andesite. Where a Carboniferous unit is present above the unconformity in Bolivia, the angle between this unit and the Devonian strata below is not greater than 5°.

INTERPRETATIONS

Lithofacies-Isopach

Figure 2 is a fence diagram of the sections measured and briefly described in Appendix 1. Lithologic correlation has been made between the sections. The sections follow the longitude of each locality (Fig. 1), but for clearer presentation, the latitudes of some have been adjusted slightly.

Several trends can be observed in the diagram: (1) All sections thin from north to south and from west to east. (2) A number of quartzose sand beds pinch out from west to east. (3) Local sandy units are seen in the east (Gamoneda), and they seem to have no western correlatives. (4) The proportion of muddy and silty beds on the east increases relative to sandy units. (5) The uppermost nonmarine beds at Belén-Pujravi may be represented by thin units at some of the eastern or southern localities. (6) The same percentage of rock column occurs above and below *Tropidoleptus* in all sections. (7) The absence of either *Tropidoleptus* or *Scaphiocoelia* (or *Pleurothyrella*) in some sections is due to that particular horizon in those sections representing another depth environment in which these taxa will not live; that is, the absence of a taxon is due to an ecologic, not a temporal, boundary. (8) If and when lower portions of the sections at Hinchaka-Huako are located, they should prove to be thicker and coarser in texture than all other sections in Bolivia.

Serious gaps exist in the measured sections; that is, between Gamoneda and Belén, along the altiplano of southwestern Bolivia, and in most areas of southern to central Peru. For example, Swartz (1925) mentioned some fossils obtained near the Chilean frontier that may be Devonian.

Paleogeography

Figures 3a, 3b, and 3c show paleogeographic reconstructions for the Devonian strata of the central Andes, based upon the data summarized in Figure 2. Insufficient data exist for Peru to allow for an extension of a paleogeographic reconstruction to that region, although Devonian rocks crop out at various localities between Lake Titicaca (Newell, 1949) and Tarma, Peru (Megard, 1973).

Proximity to the shoreline in Figures 3a, 3b, and 3c is qualitatively estimated on the basis of size and roundness of grains and lithologic composition of the rocks. It is apparent from the isopach data that proximity to the shoreline does not imply proximity to the source area. The position of the "zero isopach" line is a function of post-Devonian erosion. Phase boundaries are chosen for convenience of identifying definite lithologic breaks in the depositional scheme, as well as probable changes in proximity of the shoreline.

The interval of deposition depicted in Figure 3a is defined as the interval between the Silurian quartzite and the top of the siltstone-sandstone that contains the *Scaphiocoelia-Pleurothyrella* zone in many of the sections.

In Figure 3b, isopach and lithofacies data are placed for strata between the top of the siltstone and sandstone described for Figure 3a and the lower contact of the sandstone that contains the *Tropidoleptus* zone in most sections. This does not imply that the time of deposition for the first phase is equal to that of the second

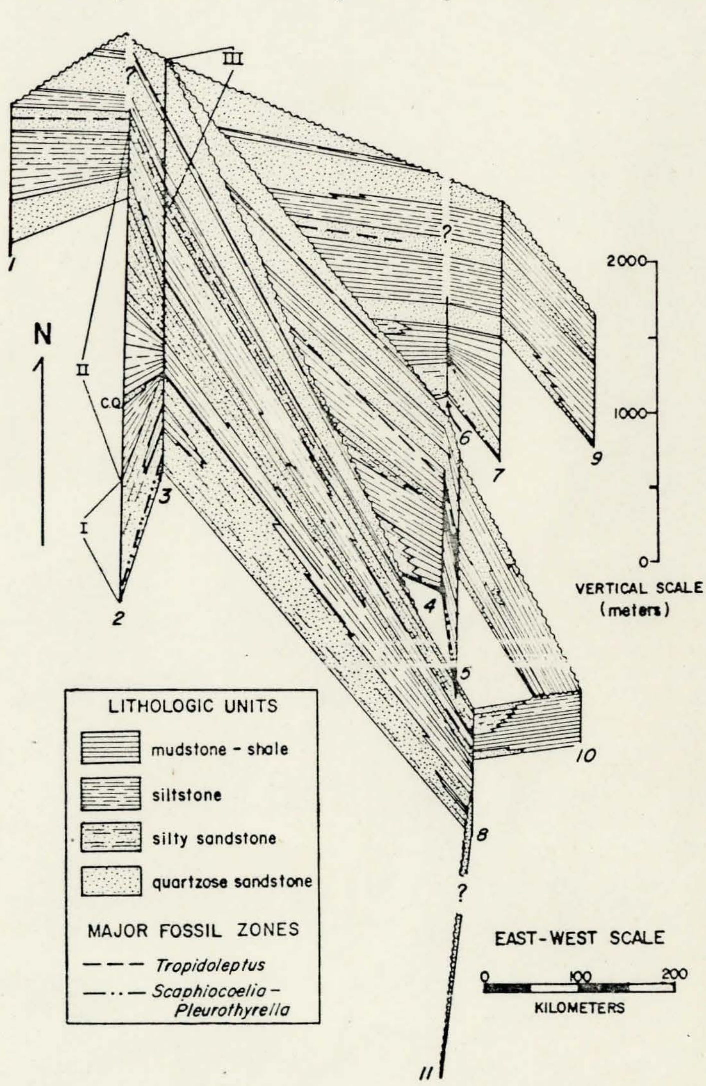

Figure 2. Fence diagram of Devonian of Bolivia. Numbers on diagram refer to locations of measured sections (see Appendix 1) as follows: 1, Hinchaka–Huako–Isla del Sol (La Paz Department); 2, Ayo Ayo (La Paz Department); 3, Belén-Pujravi (La Paz Department); 4, Presto (Chuquisaca Department); 5, Icla–Cha-kjeri (Chuquisaca Department); 6, Pojo (Cochabamba Department); 7, Quebrada del Quilco (Santa Cruz Department); 8, Gamoneda (Tarija Department); 9, Lajas (Santa Cruz Department); 10, Los Monos (Tarija Department); 11, La Mendieta (Jujuy Province, Argentina). C.Q. = Condoriquiña Quartzite; I, II, III refer to portions of columns included in depositional phases 1, 2, and 3, respectively. Figure drawn without palinspastic correction.

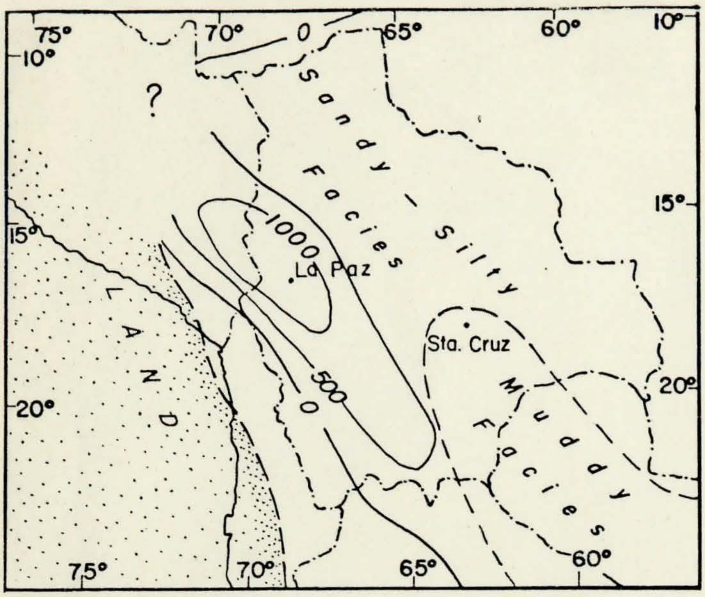

Figure 3a. Paleogeographic reconstruction of first phase of deposition in central Andean intracratonic basin, showing proposed shoreline and location of western land source area. Isopachs in meters.

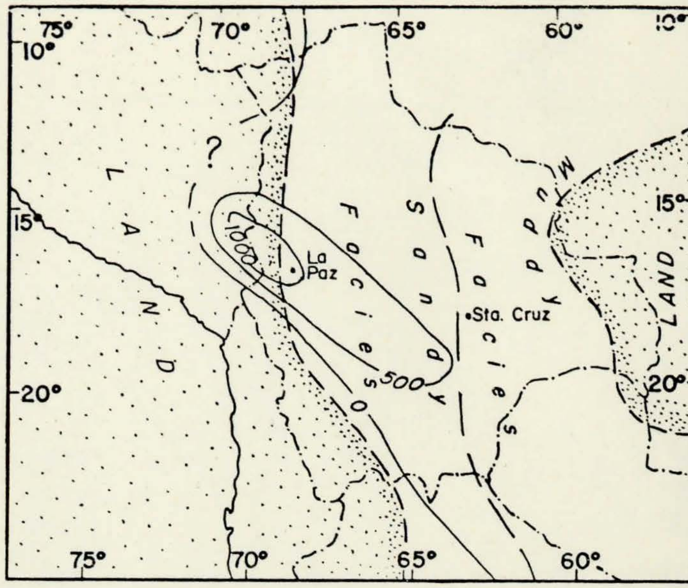

Figure 3b. Paleogeographic reconstruction of second phase of deposition in central Andean intracratonic basin, showing proposed shoreline that has migrated westward since first phase (Fig. 3a). Isopachs dashed where unsupported by data.

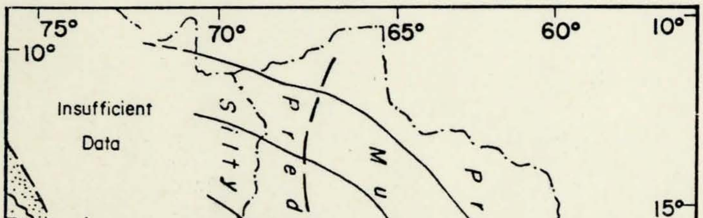

Figure 3c. Paleogeographic reconstruction of third and final phase of deposition in central Andean intracratonic basin, showing proposed eastward migration of shoreline, large accumulation of nonmarine units, and emergence of Brazilian Shield to add very small terrigenous influx from east.

phase, or, for that matter, that of the third phase. The second phase of deposition represents a direction of transgression *to the west,* as evidenced by the over-all fining of the lithofacies during the second phase.

In Figure 3c, data for the third and final phase of recorded Devonian deposition in the basin include strata between the base of the *Tropidoleptus* zone and the unconformity that terminates all of the sections. Considering the presence of nonmarine sediments at Pujravi, it is estimated that the shoreline during the third phase migrated east to a position near La Paz. This interval indicates a significant marine regression, to the extent that emergence of the Brazilian Shield possibly produced a terrigenous input in the east, as evidenced in the Gamoneda section and the sequence at Chiquitos (Barbosa, 1948; Ahlfeld, 1956; Chamot, 1963).

Data for southern and central Peru (Harrington, 1967; Megard and others, 1971; Megard, 1973; G. Laubacher, 1972, oral commun.) suggest that a possible thinning of the Devonian rocks occurs toward central Peru as far as the vicinity of Huanuco-Huancayo, where the section seems to "grade into phyllites and quartzites" (Harrington, 1967, p. 654).

Volume of Sediments

Either the source area for sediments contributed to the Bolivian portion of the central Andean intracratonic basin could have been a belt of basement rocks occupying an area equal to that of the Cordillera Occidental (Fig. 4), or a larger, now unexposed, western land mass adjacent to the coast of present-day South America (Fig. 4) could have contributed the sediments. A northwestern source is unlikely, because of the thinner and finer grained units in southern Peru (G. Laubacher, 1972, oral commun.).

The point-count method for calculating sedimentary volumes outlined by Gilluly and others (1970) was not employed, because thicknesses of Devonian rocks beyond those discussed in Appendix 1 are relatively unknown, and because the extent of the Devonian strata remains poorly understood. Instead, a shape consisting of a pyramid resting on a triangular slab was created to determine the approximate volume of the prism of Devonian rocks in most of Bolivia. The dimensions of the pyramid are the distances between farthest localities (1,000 km) and thicknesses of a 4,000-m maximum (restored isopach interpretation in the northwest) to an 850-m minimum (east and southeast). The volume of this pyramid, and hence the *minimum* volume of the Devonian in the Bolivian portion of the central Andean intracratonic basin is 8.4×10^5 km^3. If the source area were that approximated by the area outlined by hatch marks on Figure 4, or 1.7×10^5 km^2, that area would have had to be uplifted 5 km to supply sediments to fill the above volume, assuming no sediments were shed to the west of the source area. If such an uplift had occurred, a distinctively different sedimentary record would show coarser clastic material, fewer fossils, such sedimentary structures as scour and fill, and poorly sorted sediments with immature grains.

The stippled area of Figure 4, combined with the hatched area

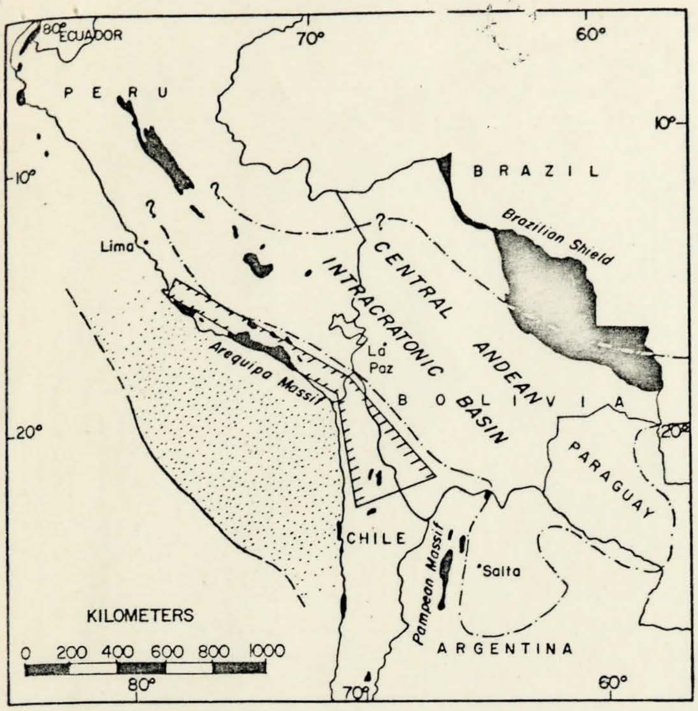

Figure 4. Paleogeographic model for central Andes during Devonian. Black lines = international boundaries; dashed-dotted lines = approximate boundaries of central Andean intracratonic basin during maximum transgression. Data for northwestern Argentina from Padula and others (1967); data for Paraguay from Harrington (in Boucot, 1971). Solid black areas = outcrop areas of metamorphic and igneous basement rocks as they appear today. Outcrop data for Peru from Hosmer (1959), Dalmayrac and others (1971), and G. Shepard (1973, written commun.); Bolivian data from Servicio Geológico de Bolivia (1968); Argentine data from Turner (1964, 1970); and Chilean data from González-Bonorino and Aguirre (1970); Brazilian outcrop data are not included. Area outlined by hatch marks = area considered in sedimentary volume calculations, assuming that no additional western land mass existed. Dotted area = minimum area of additional western land mass that is postulated to have existed during Devonian Period.

discussed above gives an area of 9.4×10^5 km^2. Even an area of this size appears to be too small to have supplied the sediments. Though an uplift of 1 km to supply the volume needed is reasonable, consideration must be given to the sediments shed *to the west* also and to the sediments contributed from the Brazilian Shield. Hence, an area of the size proposed in Figure 4 was uplifted 2 km, or one of at least twice the proposed surface area was present during the Devonian Period, since contributions from eastern or northern sources, if any, were probably small.

Basement Outcrops in the Western Cordillera

There are many reports of metamorphic and igneous basement rocks in the Cordillera Occidental and on the South American coast from northern Peru to southern Chile. Figure 4 delineates present-day outcrops of such rocks. Peruvian localities consist of various metamorphic lithologies and are numerous (Douglas, 1920; Jenks, 1946; Oppenheim, 1946; Hosmer, 1959; Dalmayrac and others, 1971; Megard and others, 1971; Martinez and others, 1972; Megard, 1973; G. Shepard, 1973, written commun.). The Peruvian portion of Figure 4 shows outcrops of Precambrian rocks there, reported by the above authors. Ruiz and others (1961) and González-Bonorino and Aguirre (1970) outlined in northern Chile outcrops of metamorphic and granitic basement rocks that had previously been considered as Precambrian by Gerth (1932). Radiometric dates from rocks of various localities throughout Chile led them to conclude that the oldest age for metamorphism of these rocks was late Paleozoic, and that no Precambrian rocks were recognized in Chile. Outcrops of "metamorphic basement" rocks in northern Chile are few (Harrington, 1961, p. 172; González-Bonorino and Aguirre, 1970, p. 980), because Mesozoic and Tertiary volcanism and plutonism have obscured the early history of the region. For similar reasons, no Precambrian rocks have been cited for western Bolivia, although extensive outcrops of the Brazilian Shield occur in eastern Bolivia (Servicio Geológico de Bolivia, 1968, p. 17). Upper Precambrian metamorphic and granitic rocks and Silurian granite occur in northwestern Argentina (Turner, 1964, p. 23–26; 1970, p. 1032–1035, 1042–1043). These rocks support the thesis that sialic basement bounds the Devonian basin. Helwig (1973, p. 1494) felt that the western Cordillera "became emergent prior to the Carboniferous." I believe that emergence took place before Devonian time.

CONCLUSIONS

1. A large accumulation of Devonian shallow marine to nonmarine clastic sedimentation in Bolivia contains no sediments that would suggest a eugeosynclinal environment of deposition.

2. Maintenance of the shallow environment of deposition along with thicker and coarser accumulations of strata in northwestern Bolivia necessitate an almost exclusively western land source for these sediments.

3. The size of the western land source that yielded the volume of sedimentary detritus in the Bolivian portion of the basin alone suggests that more land area existed in the western South American continent than exists today.

4. Abundance of detrital mica in the sediments indicates that there was a provenance area of highly micaceous rocks like those that crop out in the Cordillera Occidental today.

5. The idea of a western land source is not new (see Miller, 1970, for a discussion of the disappearance of such an area), but this paper offers additional evidence for its existence.

6. Middle to Late Devonian orogenic activity may have occurred in the interior of such a source area, although only epeirogenesis affected the central Andean intracratonic basin.

7. A western land source model suggests that many early concepts of the mid-Paleozoic history of the central Andes need revision, and that more detailed sedimentologic data (such as paleocurrents) are necessary.

APPENDIX 1. MEASURED SECTIONS

Devonian rocks are best exposed along the flanks of synclines and anticlines in the Cordillera Oriental and Sierras Subandinas of the Andes Mountains in the western two-thirds of Bolivia. Strata are also exposed in the altiplano between Oruro and La Paz, extending through Lake Titicaca into southern Peru. Other sections are at Rurrenbaque (Diaz, 1959; G. A. Chamot, 1969, unpub. data), Roboré (Barbosa, 1948, Ahlfeld, 1956; Chamot, 1963), and the Cabañillas region of Peru (Newell, 1949; G. Laubacher, 1972, oral commun.); these are essentially unmeasured. The sections that were measured are shown in Figure 1. Brief descriptions of the lithologic and paleontologic character and of over-all thicknesses of the sections follows: Numbers following locality names refer to the columns assembled in Figure 2. Formational names have been largely avoided to eliminate confusion of differing usages of stratigraphic names.

Hinchaka–Huako–Isla del Sol (1)

Section — 910 m of Devonian. The rocks begin at the shore of Lake Titicaca, where gently dipping beds of fine-grained, micaceous, and quartzose sandstone (200 m) are medium bedded, well cemented with silica, and exhibit ripple marks. Uppermost beds of the sandstone yield abundant specimens of the brachiopod *Metaplasia*, almost exclusively. Overlying this sandstone are micaceous mudstone and silty mudstone (450 m), with some siltstone interbeds. Fossils from this sequence are rare. The top 75 to 80 m of the section contains medium-grained, quartzose (approximately 80 percent quartz) sandstone, which is thickly bedded and well cemented. The lower portion of the sandstone yields the brachiopod *Tropidoleptus*. A subtle angular unconformity (approximately 2° to 3°) separates the sandstone from Carboniferous arkosic sandstone, diamictite, dune sand, and coal beds. Ascarrunz and Radelli (1964) included the diamictite in their Devonian section, thus indicating that they did not recognize the angular unconformity.

Ayo Ayo (2)

Section — 3,300 m of Devonian. Although this section is incomplete, it is by far the thickest encountered in Bolivia. Immediately above Silurian quartzite follows micaceous, sandy siltstone (750 m), with the brachiopod *Scaphiocoelia*. Above this unit commences mudstone (800 m), with sparse interbeds of indurated siltstone and fine-grained, thinly bedded sandstone. Fossils above the lowermost siltstone are rare. One explanation for this is that the Ayo Ayo section records the highest apparent rate of sedimentation of those measured in Bolivia; the fossils are diluted by a high sediment input. This depositional environment may have been too turbid for brachiopod survival (Heckel, 1972, p. 250). A distinct cliff-forming quartzite unit interrupts the mudstone-siltstone sequence.

Called the Condoriquiña Quartzite (named by Ahlfeld and Branisa, 1960, p. 66), this unit consists of 30 m of fine- to medium-grained micaceous and quartzose (90 percent quartz) sandstone with subangular grains; it is massively bedded and well cemented. A monolithologic, rarely fossiliferous 1,000-m interval of siltstone and mudstone of variable bedding thickness follows; the top is marked by a distinctive, medium-bedded, micaceous, limonite-bearing sandstone. Above this unit the section becomes sandier and more quartzose, with silty and muddy beds becoming subordinate. A *Tropidoleptus*-bearing sandstone (fine grained, slightly quartzose [70 percent], thickly bedded, cliff forming) is approximately 300 m above the previous cliff-forming sandstone. Above this last sandstone is mudstone, in which a goniatite cephalopod was reported (Lizarazu, 1969; L. Branisa, 1972, oral commun.), with an age range of early Eifelian to late Givetian. This occurrence may indicate an upper age limit for the Devonian sequence at Ayo Ayo. Tertiary lacustrine deposits lie on the mudstone with angular unconformity.

Belén-Pujravi (3)

Section — 2,700 m of Devonian. Beginning at a Silurian quartzite contact, the section contains 200 m of sandy siltstone, similar to that at Ayo Ayo, and bears *Scaphiocoelia* and a few carbonate nodules. The next 800 m consists mainly of mudstone and siltstone that contain argillaceous carbonate nodules, which are fossiliferous. The Condoriquiña Quartzite, similar to that at Ayo Ayo, follows. The top 800 m is chiefly angular grained, massively bedded, micaceous and quartzose sandstone with *Tropidoleptus* at the base and cubic solution pits, which were presumably filled with halite, at the top. Because there does not appear to be an angular unconformity between any part of the sandstone, and because the sandstone appears not to resemble Carboniferous units described from Bolivia, this portion of the section is interpreted to be nonmarine Devonian. Tertiary deposits lie unconformably over the sandstone.

Presto (4)

Section — 740 m of Devonian. Immediately above Silurian quartzite is the trace fossil *Arthrophycus* in a medium-grained sandstone (5 m), which is medium bedded, angular grained, and well cemented. L. Branisa (1972, oral commun.) has reported *Scaphiocoelia* from the same bed, but I recovered none. Shale (550 m) occupies the central portion of the section, and fossils occur at various levels, some in carbonate nodules 30 to 40 cm in diameter, others randomly in the shale. Large spiriferid brachiopods are the chief fossil type found in this unit. The trace fossil *Zoophycos* marks the upward change in lithology to a fine- to medium-grained sandstone (100 m), which is massively bedded and consists of varying amounts of quartz, from 40 to 90 percent. Muscovite is found abundantly in all lithologies. The top of the section is the eroded ground surface.

Icla–Cha-kjeri (5)

Section — 1,650 m of Devonian. Immediately above Silurian quartzite is densely fossiliferous sandstone (5 m), with *Scaphiocoelia* being a conspicuous occupant among many brachiopod genera in this unit. This medium grained sandstone is medium bedded, well cemented, and moderately well sorted. Asymmetrical interference ripple marks are on many bedding surfaces, with many fossils being found in their troughs. The ripple marks are aligned in a northeast-trending orientation. Dark-gray to brown shale (570 m) follows, containing carbonate nodules with conularids, hyolithids, and trilobites in the middle of the unit. Three sand units (10 m each) form small cliffs slightly below the zone of nodules. *Zoophycos*-bearing siltstone follows, marking the beginning of a coarser grained sequence. *Tropidoleptus* occurs in a siltstone-mudstone sequence; *Globithyris*, the shallowest articulate brachiopod found in Bolivia (Isaacson, 1974b), occurs in the uppermost sandstone (80 m) of the section. This medium-grained, medium-bedded quartzose (90 percent) sandstone contains angular grains. The top of the section is marked by an erosional unconformity between Devonian and Tertiary andesite (G. A. Chamot, unpub. data).

Pojo (6)

Section — 650 m of Devonian. Fine-grained, thinly bedded sandstone (250 m), that gradationally overlies Silurian quartzite, contains intertidal brachiopods, such as *Pleurothyrella*, *Proboscidina*, and *Australocoelia*. Sparsely fossiliferous black shale (195 m) follows. The remainder of the section is mainly fine- to medium-grained sandstone that contains subrounded grains for the most part and has thin to medium bedding. The sandstone has some ripple marks, cross-bedding, and siltstone partings.

Quebrada del Quilco (7)

Section — 1,740 m of Devonian. The section begins with fine-grained, well-cemented silty sandstone (80 m) that contains interference ripple marks. Abundant brachiopods (*Proboscidina*) have accumulated in the troughs of the ripple marks. Black micaceous shale and mudstone (600 m) follows, with rare fossils. The brachiopod *Pleurothyrella* is an important element in the lower 5 m of the unit. An abrupt lithologic change to *Zoophycos*-bearing siltstone marks a new sequence (800 m) of siltstone and fine-grained, micaceous, and medium-bedded sandstone with rare fossils. Dominant among the few fossils are conularids, tentaculitids, plant fragments, and bivalves. Inasmuch as bivalves occur stratigraphically above the plants, I have concluded that these plants were marine or at least were deposited in a marine environment. Tertiary lacustrine deposits are angularly unconformable on the Devonian.

Gamoneda (8)

Section — 860 m of Devonian. Overlying the Silurian quartzite, the Devonian sequence commences with siltstone (500 m), some beds of which bear small-scale planar cross-stratification and abundant and diverse brachiopods. Fossiliferous mudstone and siltstone comprise most of the section. A micaceous medium-grained sandstone (50 m), which is medium bedded and friable, terminates the section. In this sandstone are Devonian spiriferid brachiopods, with plants above them. Until positive identification of the plants is made, a Devonian age assignment of the uppermost portion of the section is tentative, for the plants could be Carboniferous in age. Tertiary lacustrine sediments lie with angular unconformity on the Devonian.

Lajas (9)

Section — 800 m of Devonian exposed. This section is predominantly siltstone and mudstone and is incomplete. Only the upper part of the section is exposed. Fine-grained, micaceous, and thin-bedded sandstone interbeds (20 m each) occur in the exposed portion of the section. Fossils are rare. The top of the section is marked by an erosional unconformity, separating the Devonian from massively bedded Carboniferous sandstones.

Los Monos (10)

Section — approximately 450 m of Devonian exposed. H. J. Harrington (1973, written commun.) reported on the section as follows: " . . . the wells drilled near the anticlinal crest . . . encountered more than 1000 meters of Los Monos Formation (Devonian) and bottomed in this unit . . . . The exposed Devonian consists of mudstones, shales, siltstones, sandstones, and several *limestone* [Harrington's emphasis] beds 0.5 to 1.0 thick individually, which can be easily mistaken for sandstone." The top of the section is marked by an unconformity between the Devonian and Mississippian fluviatile sandstones (Harrington, 1973, written commun.). Homalonotid trilobites collected near the top of the section indicate a very shallow marine (high intertidal) environment of deposition (see discussion above).

La Mendieta, Argentina (11)

Section — 21 m of Devonian. Fifteen meters of medium-grained, quartzose (90 percent) sandstone is well cemented, medium to thickly bedded, and exhibits cross-bedding. Shale (6 m) follows with rare fossils. The top of the section is an eroded surface.

ACKNOWLEDGMENTS

Field studies were carried out with the assistance of Laurie Isaacson and Belarmino Antelo, of Universidad Nacional de La Plata, Argentina. The field work consisted of identification, location, description and measurement, and collection from as many geographically dispersed and complete Devonian sections as was feasible in two field seasons, 1971 and 1972. Sincere appreciation is extended Leonardo Branisa of La Paz, for his guidance to heretofore unpublished sections, and to H. J. Harrington, Buenos Aires, for his valuable assistance with references and comments on a previous manuscript. V. F. Hollister and J. Helwig critically reviewed an earlier manuscript; appreciation is also extended to A. J. Boucot and J. G. Johnson for their encouragement and constructive criticism of the manuscript.

This work has been primarily supported by National Science Foundation Grant No. GA-17764.

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Manuscript Received by the Society January 14, 1974
Revised Manuscript Received April 26, 1974